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MEMORANDUM REPORT ARBRL-MR-03008

HAWK TRANSFER FUNCTION EXPERIMENTS: PROJECT HAVE NAME

William F. Braerman
John A. Morrissey
Clifford Taylor

April 1980

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

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Sticky Cylinder Detector
Simulant Dispenser
Hawk Battery
Exposure

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A very integral part of the Army HAVENAME vulnerability model was the internal distribution factor for the Army selected target, a HAWK battery. This internal distribution factor had to be measured using a major item of a Hawk battery. Because of the possible damage carbon fibers might cause to the electrical/electronic components of a Hawk major item, it was necessary to measure the internal distribution factor using a non-conducting, aerodynamic simulant for carbon fibers. This report describes the fiber simulant selected, the dispersing method, the detection method, and the data analysis.

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1. INTRODUCTION

The Army, as a part of the Tri-Service HAVE NAME [HN] program, was committed to develop a vulnerability model which could be used to assess the vulnerability of an Army system to the carbon fiber [CF] threat, if it existed. The model developed is an exponential model and can be written as

$$P_k = 1 - \exp\left(\frac{-fwE}{\langle E \rangle}\right) \qquad (1)$$

where P_k is the probability of failure, f is the input filter factor, w is the internal distribution parameter, E is the outside exposure, and $\langle E \rangle$ is the average exposure to failure. For a more complete explanation of the exponential model, refer to references 1 and 2. The intent of this work is to measure the internal distribution paramenter, w.

The system chosen to exercise the vulnerability model on was the HAWK Air Defense Missle System. Because of the expense and non-availability of major items of the HAWK System and the unknown future effects of CF on these items, vulnerability measurement of these systems had to be done by a non-destructive method. The approach that was adopted to determine the HAWK vulnerability was to expose major items to an aerodynamic simulant for the purpose of establishing the internal distribution parameter to the major item's vulnerable components [power supplies, amplifiers, etc.]. These components were then individually tested with CF, to determine their $\langle E \rangle$, average exposure to failure. The input filters for all items were tested in a separate experimental setup to determine the filter factor, f. After the variables f, w, and $\langle E \rangle$ had been established, it was possible to estimate from a known outside exposure, E, a P_k for a major item using equation (1). Further application of vulnerability theory would yield the P_k for a complete HAWK Battery.

2. EXPERIMENTAL PROCEDURE

Because it was necessary that the simulant material be a nonconducting fiber, the active fiber detection method, the BRL ball gauge, was not useful. In this section of the report, the simulant material, the dispensing system, and the detector system will be discussed along with a description of a typical trial procedure.

[1] *R. D. Shelton and J. R. Moore, "Vulnerability of the Improved Hawk System (U)," BRL Report No. 1964, February 1977, SECRET.*

[2] *R. D. Shelton and J. R. Moore, "A HAVE NAME Vulnerability Model (U)," BRL Report No. 1912, August 1976, SECRET.*

2.1 Simulant Material

The HAWK component vulnerability tests were performed using Hercules HMS carbon fibers. The simulant selected for the internal distribution parameter measurements was Baked Kevlar 49*. The density and diameter of a Kevlar fiber are nominally 1.5 g/cm^3 and 10μ respectively, as compared to 1.87 g/cm^3 and 8μ for a Hercules HMS fiber and both fibers have equal settling velocities, 1.5 m/min. The simulant was cut into 7 mm lengths, the length selected for the component vulnerability testing, and packaged in 250 mg units.

2.2 The Dispensing System

The experiments were designed so the simulant could be introduced into the item under test in a controlled and repeatable manner. The material was slowly fed into a one cubic meter box by the venturi action of a high pressure air flow line [100-120 psi]. The high flow served to separate the simulant material into single fibers which could then be exhausted from the mixing chamber by means of the normal air intake of the item under test. All adaptors were made so that the mixing chamber was connected to the major item's air intake by means of a 8.5 cm diameter input duct. In figure 1, the mixing chamber and connecting duct work can be seen attached to the input of the transmitter section of the Improved High Powered Illuminator [IHPI]. Other sections which underwent test, such as the Radar section on the right, and the Liquid Cooler and the Antenna section in the center, can also be seen in the same figure.

A major concern for the dispensing method was its efficiency and if it would cause any fiber break-up. Measurements showed a dispensing efficiency for single fibers of 95% and less than 5% of the observed fibers had experienced any length breakup.

2.3 Detectors

Because the simulant by necessity had to be a nonconducting fiber, and as such could not be counted using active detection systems such as the charge transfer technique, it became necessary to develop a passive detection system. The method determined best was a piece of sticky paper formed into a cylinder with the dimensions 1.3 cm diameter at the base and 3.8 cm high. The dimensions were chosen such that when the cylinder was split, it could be placed flat on a standard 35 mm slide. The use of the 35 mm slide had two main advantages: 1) easy storage and marking while performing the experiment in the files and 2) easy projection and magnification for the counting and data analysis. Figure 2 shows the sticky paper cylindrical detector and the viewing slide.

* Celanese Research Company, Summit, N.J.

Figure 1. View of Simulant Input to IHPI

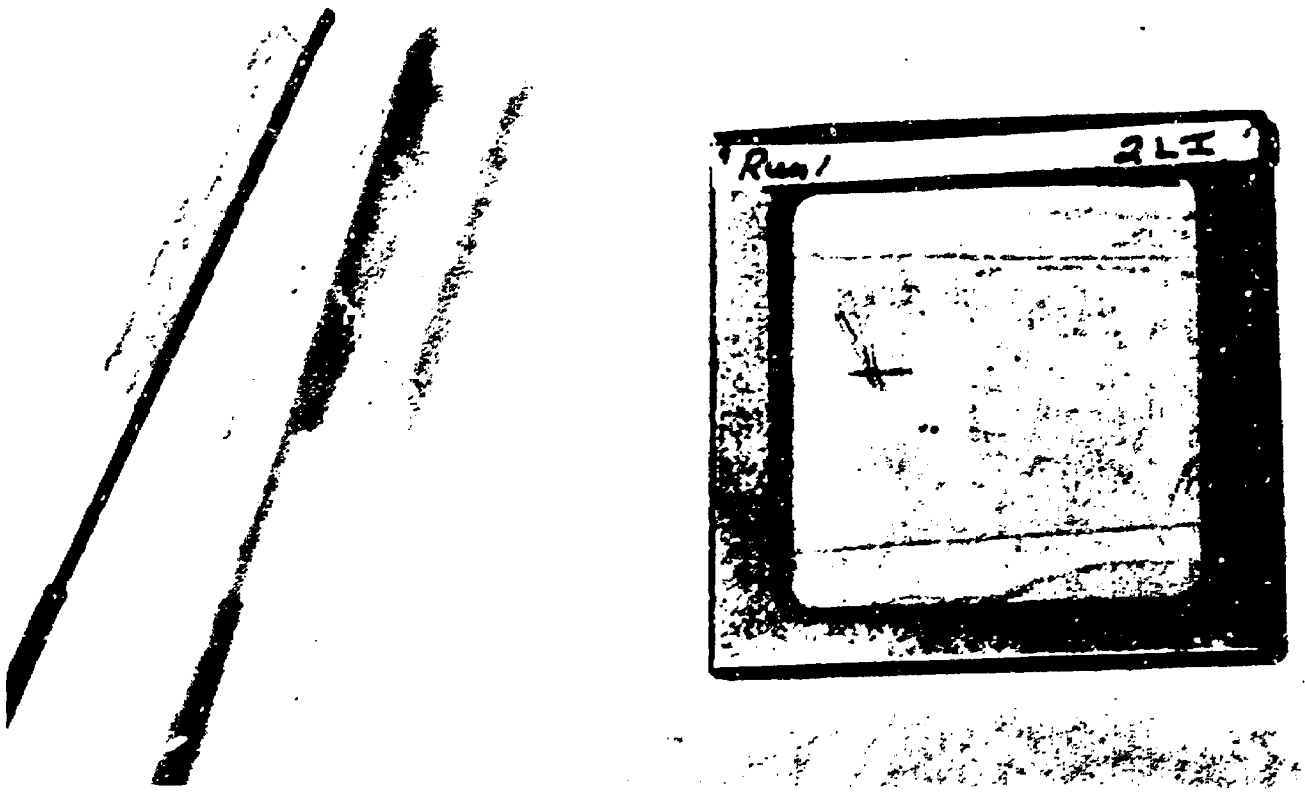

Figure 2. Sticky Tape Detector System

2.3.1 Detector Calibration

The relationship between the counts on the sticky detector and exposure can be written

$$E = \frac{C_{st}}{K\,[u]} \qquad (2)$$

where E is the exposure, K[u] is the calibration constant, a function of velocity, and C_{st} is the total counts on a sticky detector. Since this calibration was performed using the ball gauge as a standard, the same type physical notation was applied where

$$K[u] = V_{eff} \qquad (3)$$

where V_{eff} is the effective sampling volume of the sticky cylinder detector. This effective sampling volume of the sticky cylinder detector was determined relative to that of the ball gauge. Figure 3 shows the effective volume of the sticky cylinder detector versus fiber velocity. It can be seen that within the air flow ranges common in the HAWK cooling systems (100-600 fp), the effective volume is approximately constant. Because of this, exposures at different detector positions can be compared by total counts per detector without regard to fiber velocity in the vicinity of the detector. For further information about the calibration, see reference 3.

2.4 A Typical Trial Procedure

Since it was known from previous work that the HAWK input filter factor, f, was approximately 10%, it was decided to perform the transmission function trials without the input filter in place on the section being tested for better counting statistics in the data analysis. Each section of the HAWK included many components, and judgment was made in the field as to the number of detectors to be placed in each component and the position of these detectors. Some considerations given to the number of detectors and their position were: 1) counting problems, 2) easy placement, 3) existence of air flow in the region of the detector, and 4) high probability of fibers getting to the region. The monitor or standard for each trial was a sticky cylinder detector in the center of the input duct. Figure 4 shows the instrumentation of a typical component. Detector placement is shown by the pointers on the photo.

After the positions had been selected and the detectors were in place, the trial was begun. The air circulator for the item to be

[3] *John A. Morrissey, William I. Brannan, and Samuel C. Thompson, "Calibration BRL Ball and Sticky Cylinder Detector System", Ballistic Research Laboratory, Technical Report ARBRL-TR-02079, Jun 78, (UNCLASSIFIED).* (AD #B029204L)

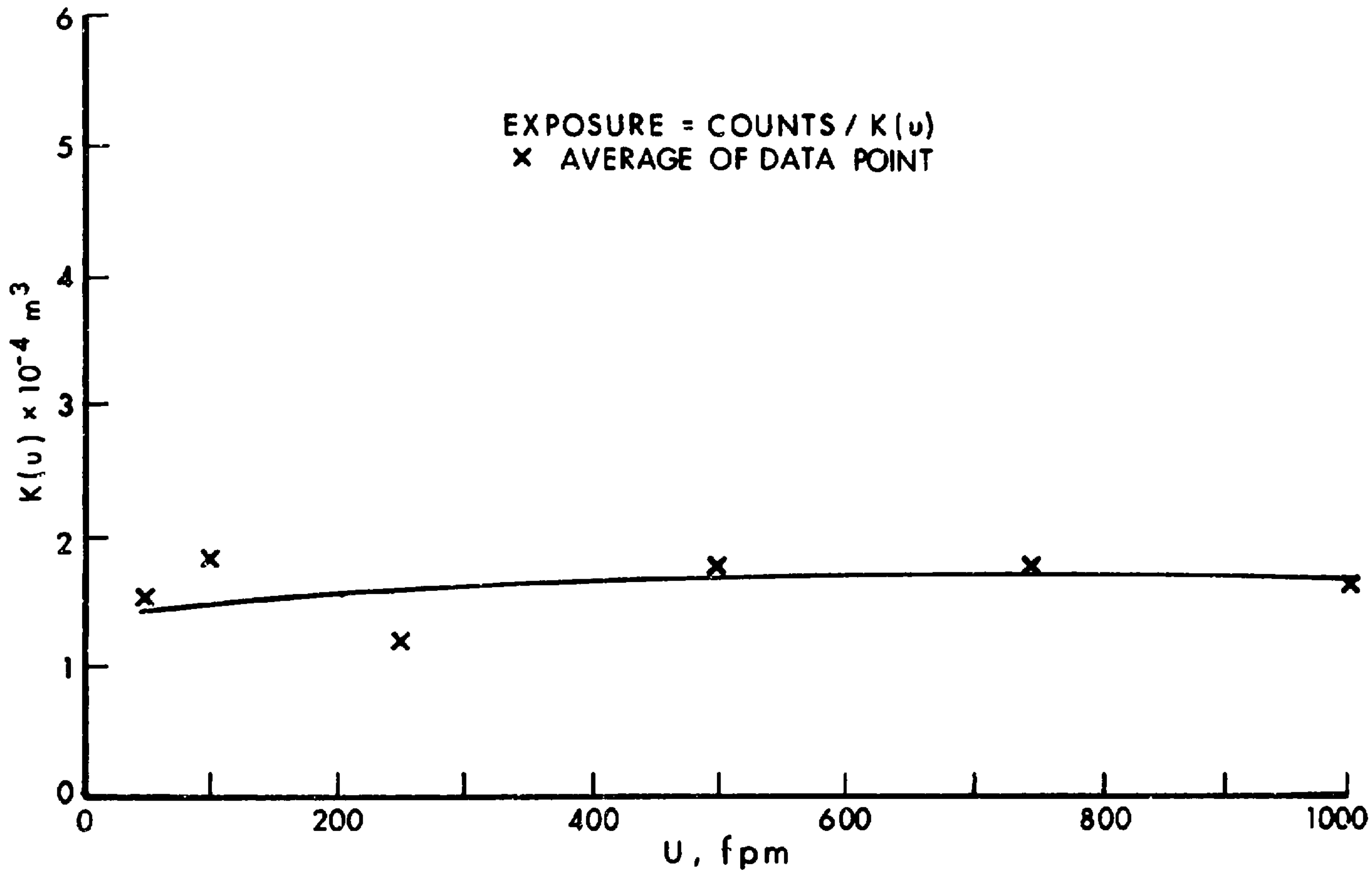

Figure 3. Sticky Tape Calibration Curve

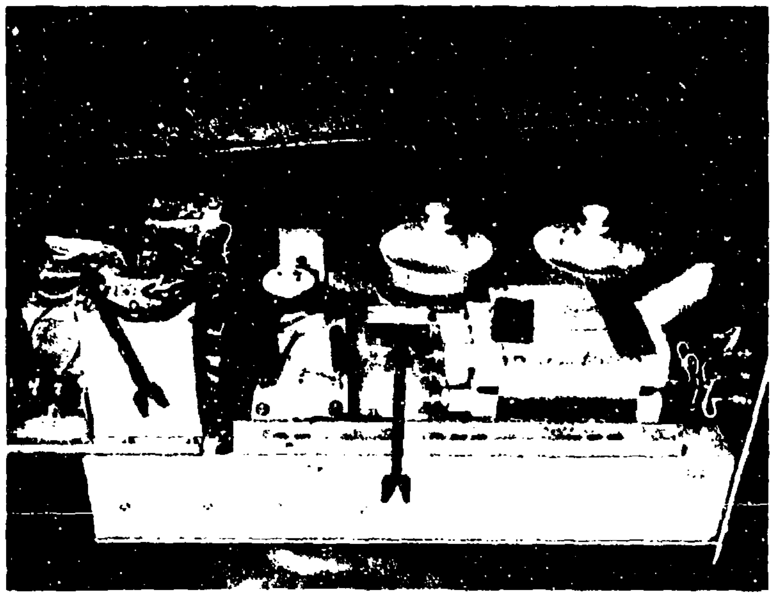

Figure 4. View of Typical Detector Placement

tested was activated and the simulant, which was being fed slowly into the dispensing box, was drawn into the item by its air circulating system. One package (250 mg) of the simulant was dispensed over a 2 minute period.

The test item's air system, however, was operated a total of 5 minutes, to insure sufficient time for transmission through the complete system. The unit was then shut down, and the detectors were removed, marked, and placed on glass slides for easy storage until they could be counted at a later time.

At the time these trials were being made, there was some concern for the amount of exposure which might be delivered by residual material from a startup procedure and a long operation. To study this effect, the unit was completely reinstrumented and operated for an hour. These studies showed that this residual effect could be as high as 20% at some locations.

For each unit tested, this complete process was done twice. Between trials, the item was completely vacuumed, brushed, and sprayed with a high flow of air, to remove any remaining simulant fibers. Tests had shown this cleaning procedure to be greater than 95% effective.

2.5 Data Analysis Method

Because the calibration constant is independent of velocity, the internal distribution parameter, w, is simply a ratio of detector counts.

$$w = \frac{N_i}{N_o} \tag{4}$$

where N_i is the summation of the five minute and hour operation for the i, th detector, and N_o is the same summation of the input detectors. The internal distribution is the average of the two trials.

3. DATA SUMMARY

Figure 5 is a schematic of a HAWK battery. Two major items, the Improved Battery Control Center (IBCC) with its CBR protection and the launcher were not tested because they were judged nonpenetrable and invulnerable respectively. A third item, the Improved Range Only Radar (IROR), was not tested because its nonoperation would not severly hinder the operation of the HAWK batter. Table I lists the tested major items along with their sub-assemblies. A brief discussion of each tested item follows.

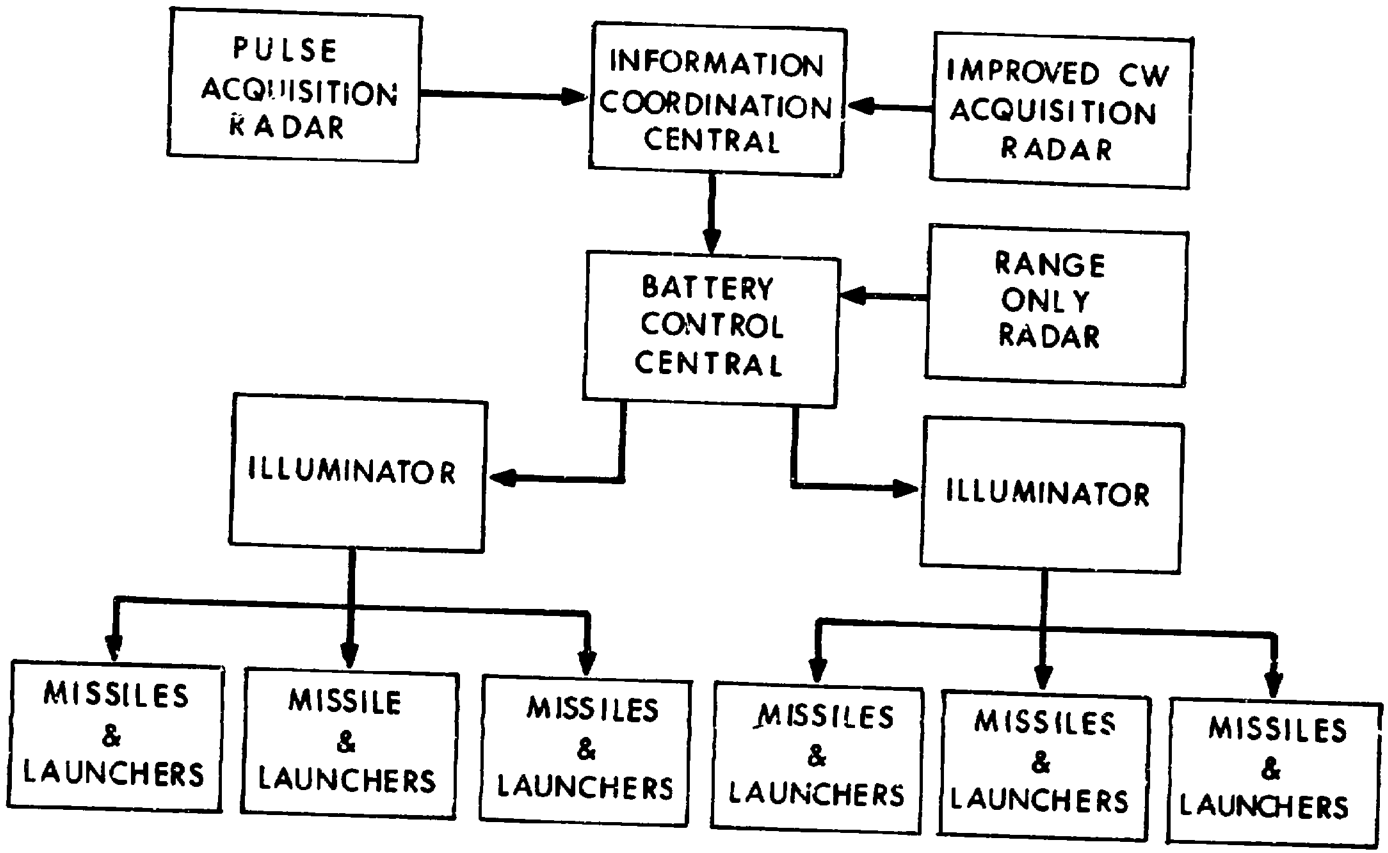

Figure 5. HAWK Battery Layout

TABLE I HAWK ITEMS TESTED WITH SIMULANT

Low Powered Illuminator
- Radar Section

Improved High Powered Illuminator
- Transmitter Section
- Radar Section
- Antenna Assembly
- Motor Generator Assembly
- Liquid Cooler Assembly

Improved Continuous Wave Acquisition Radar
- Radar Section
- Motor Generator Assembly

Improved Platoon Command Post
- Main Console Area
- Automatic Data Processor

Improved Pulsed Acquisition Radar
- Radar Set Group
- Amplifier-Cooler Group

3.1 Low Powered Illuminator [LPI]

Because it is no longer an intergral part of the Improved HAWK System, the LPI was a major item which was available for an active CF test. This item is the one which was used for vulnerability validation tests both in the laboratory[4] and the field.[5] To judge the simulant experiment performance, a simulant test of the LPI was performed in the laboratory. The LPI is composed of 3 major sections, the radar section, the antenna pedestal, and the motor generator assembly. The only section tested was the radar section. Transmission to the antenna pedestal and the motor generator assembly were not measured because tests of the vulnerability of the LPI were only concerned with the radar section. These distribution ratios were used to predict the vulnerability of the LPI. For more information see reference 4.

3.2 Improved High Powered Illuminator [IHPI]

The IHPI and the missile are the most essential items in the HAWK battery. The IHPI is composed of five separate sections, each having its own air intake and exhaust. Each section was tested separately. A brief discussion of each section follows, and a summary of the data can be found in Table II.

3.2.1 Transmitter Section

The Transmitter section is composed of three main cabinet sections. One is used to house the Klystron equipment, the other houses the pump for the Klystron coolant, and the third houses the sealed electronic units for the Klystron control. The air circulation is a two fan push-pull arrangement with the main feed into the cabinets through plenums connected to the air-cooled components of the system. The boxes, which require the maximum cooling and are connected directly to the cabinet input air plenum, have the highest transfer function, which is on the order of 40%.

3.2.2 Radar Section

The Radar section is composed of 11 separate cabinets and drawers. Eight of the sections are forced-air fed by a plenum. The exhaust is through filters at each end of the Radar unit. All sections were monitored with detectors including the ones which did not have a direct air-feed to them. The highest transmission factor for the Radar unit was approximately 50%.

[4] *W. F. Braerman, E. M. Vogel, J. A. Morrissey, and C. Taylor, "HAWK LOW Powered Illuminator Vulnerability Tests (U)," Technical Report ARBRL-TR-02076, June 1978, SECRET.*

[5] *E. Michael Vogel and Jill H. Smith, "Vulnerability Model Validation Testing - Project HAVE NAME (S)," Technical Report - to be published.*

TABLE II HAWK SIMULANT RESULTS

Equipment Nomenclature	Number of Detectors	Number of Units	Transfer Function % Min	Max	Average
Low Powered Illuminator Radar Section	45	12	3	30	13
Improved High Powered Illuminator Transmitter Section	22	11	0	33	10
Radar Section	45	12	1	56	19
Antenna Assembly	30	10	0	25	9
Motor Generator Assembly	3	3	1	36	22
Liquid Cooler Assembly	4	2	2	2	2
Improved Continuous Wave Acquisition Radar Radar Section	32	9	1	14	4
Motor Generator Assembly	6	4	5	15	10
Improved Platoon Command Post Main Console Area	25	∿10	2	2	2
Automatic Data Processor	30	7	1	4	2
Improved Pulsed Acquisition Radar Radar Set Group	38	5	18	78	43
Amplifier-Cooler Group	8	2	2	11	7

3.2.3 Antenna Assembly

The antenna air is drawn through an input on the side, passes down through a screen, and runs up through the slip rings into the box behind the receiver antenna which contains the electronics for the receiver system. The box behind the transmitter antenna does not have an air flow through it. The maximum transmission factor for the antenna pedestal is at the air input to the slip rings, and that transmission was on the order of 10%.

3.2.4 Motor Generator Assembly

Air input to the motor assembly is into a large volume containing the motor and the associated connectors. The exhaust is through the motor itself. Transfer functions into the motor generator area are on the order of 30%.

3.2.5 Liquid Cooler

Input into the liquid cooler cabinet is through the cooling radiator and exhausts are out the rear of the cabinet. The flow velocity is very high. Fibers are entrained in the air moving through the radiator and very little air is exchanged with that section of the cabinet containing the electronic pieces. Thus there is a minute amount of transfer of approximately 2%.

3.3 Improved Continuous Wave Acquisition Radar [ICWAR]

The ICWAR has three main sections to be tested, the Radar Section, the Motor Generator Assembly, and the Antenna assembly. Tests were not performed on the antenna assembly because of its simularity to the IHPI antenna assembly. Tests were performed on the two remaining sections and a summary of the data can be found in Table II.

3.3.1 Radar Section

The Radar Section of the ICWAR was very similar to the LPI and IHPI. The air handling system is the same as that used in the LPI and the IHPI Radar Section. There are nine separate sections all of which were instrumented to measure the CF transfer function. Two cabinets were not directly fed from the plenum. The results are a transfer function of 15% maximum.

3.3.2 Motor Generator Assembly

This motor generator assembly is the same as the one used on the IHPI and the LPI except that the input air comes through an input at each end of the unit. The air flow is approximately the same, 15 cfm. The fiber transmission function into the cabinet is approximately the

same as the IHPI, 20 to 25%.

3.4 Information Coordination Central [ICC]

Because the ICC has two separate air flow patterns, the van was divided into the main console and personnel area, and the automatic data processing area. Both areas were individually tested with simulant. These results can be found in Table II.

3.4.1 Main Console Area

This section is the main area of the van and contains the central communications units, radio sets, power supplies, etc. It is also the area occupied by the command personnel. The air handling system is an air conditioning unit with a recirculating system and a manually controllable air makeup valve. To produce a worst case scenario, the air conditioner was run in the vent mode, i.e. recirculating air but without the compressor operating, air makeup vent completely open, and the air conditioner input filter removed. The van, which is operated at a positive pressure, would have minimum fiber leakage from the outside. The maximum transfer function measured was 2%.

3.4.2 Automatic Data Processor

The air cooling system for the ADP consisted of three muffin fans at the base of each rack. The air was drawn from the outside across heaters, passed up through the racks, and exhausted through a vent in the roof. There are two input ports for the system, both of which were tested with simulant. The maximum transfer function achieved to any rack from either input was on the order of 5%.

3.5 Improved Pulsed Acquistion Radar

The IPAR trailer has four main sections, the Radar Set Group, the High Voltage Supply Group, the Receiver-Transmitter Group, and the Amplifier-Cooler Group. The Receiver-Transmitter and High Voltage Supply groups were not tested because they were sealed to outside air and a transfer function of zero was assumed. The other two groups were tested and the results are shown in Table II.

3.5.1 Radar Set Group

Because there is not much heat generation, the cooling in this system does not have to be very good. Air was circulated through the five cabinets by a small fan. The air flow through the system was on the order of 500 cfm. Also the air was not channeled, so there was a very random flow and transfer function. The maximum transfer was about 80% directly inside the input fan at some low voltage power supplies,

3.5.2 Amplifier-Cooler Group

Cooling air flow in this group was by leakage from the cooler system. The maximum transfer function in the amplifier cabinet was 2%. The cooler section had a transfer function of approximately 10% but is considered invulnerable to fibers.

4. CONCLUSIONS

1. The internal distribution parameter of the Improved HAWK battery was measured using a carbon fiber simulant, Kevlar 49. The results ranged from 2% to 80% and were dependent upon the amount of cooling required for the various component.

2. The experimental apparatus, i.e. the detectors, simulant, and dispenser, were more than adequate to perform the tests.

3. These tests were used to determine susceptible HAWK components for laboratory vulnerability testing.

4. The detectors used and their counting system were more than adequate to perform the experiment.

5. The fiber dispenser and injection system produce a minimum of fiber breakup and are very useful both in the laboratory or field environment.

ACKNOWLEDGEMENTS

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SUBJECT: Distribution Statement - Ballistic Research Laboratory Memorandum Report ARBRL-MR-03008

1. Reference: Ballistic Research Laboratory Memorandum Report ARBRL-MR-03008,"Hawk Transfer Function Experiments: Project HAVE NAME", by William F. Braerman, John A. Morrissey, and Clifford Taylor, April 1980, AD number B047354L, UNCLASSIFIED.

2. Subject matter experts from the Army Research Laboratory (ARL) and the Joint Technical Coordinating Group, and the ARL Security/CI Office have determined that the subject report may be released to the public. Request that you mark your copies of the document with the following distribution statement:

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3. Questions may be directed to Mr. Douglas J. Kingsley at commercial telephone number 410-278-6960.

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